



ASSAR

ADAPTATION AT SCALE
IN SEMI-ARID REGIONS
2014–2018



CHANGING ECOSYSTEM
SERVICES ARE INCREASING
PEOPLE'S VULNERABILITY IN
SEMI-ARID REGIONS

AN ASSAR CROSS-REGIONAL INSIGHT



Semi-arid regions are undergoing complex shifts in land-vegetation-atmosphere interactions. These shifts impact on ecosystem services, with major corresponding implications for local communities. Yet, socially-just access to key ecosystem services is an integral part of climate change adaptation, across rural and urban settings. Enhancing human wellbeing and climate resilience in the face of these changes requires governance at multiple scales to take into account the synergies and trade-offs associated with the ecosystem services that are of value to different social groups. Including affected populations more concretely in management decisions will help to identify the main trade-offs, and support more effective design and implementation of interventions. Decision makers should also capacitate customary, traditional, and community-based natural-resource managers by devolving decision-making rights to them, and by facilitating and promoting equitable and adaptive natural-resource management.

ASSAR's focus on the dynamics of ecosystem services in semi-arid regions

Across the world, ecosystem services – which can be product-based (e.g., food, water), process-related (e.g., climate regulation, hydrology), cultural (e.g., spiritual enrichment, cognitive development) and ecosystem-supporting (e.g., soil formation, nutrient cycling) – offer direct and indirect contributions to human wellbeing. In the semi-arid regions of Africa and Asia, people are particularly dependent on ecosystem services given that communities here are characteristically poor with limited access to public services and livelihood opportunities. By harnessing ecosystem services, such communities have evolved lifestyles and traditions that enable their survival even when conditions are harsh.

Recently, however, the integrity of ecosystems in these areas has been compromised by rapid growth in the human population, inadequate or unsustainable governance of resources, and the increasing intensity and severity of climate extremes. These threats have led to reduced crop yields, diminished availability of fodder and non-timber forest produce, reduced surface flows in rivers, and depleted groundwater. As changes in regional climates are expected to increase the frequency and severity of extreme weather (rain, droughts and heatwaves), these impacts are expected to intensify.



ASSAR's primary aim was to understand the factors that enhance or degrade ecosystem services, and the ways in which these services can be equitably managed and governed to improve wellbeing under climate change. In a novel south-south approach, our research saw a non-hierarchical collaboration of 16 researchers from seven countries across East, southern and West Africa, and three Indian states (Tamil Nadu, Karnataka and Maharashtra), and we worked to understand the complex changes and patterns in semi-arid vegetation and socio-ecological systems through space and time.

We mapped ecosystem changes using a cross-regional coarse-scale study that relied on AVHRR GIMMS NDVI3g and CRU climate data to capture global and regional trends, and dynamics in vegetation response to climate and non-climatic drivers – including evidence for the CO₂ fertilisation effects. We used finer-scale MODIS data (250 m) to capture recent changes that could be interpreted effectively by combining with household and village-level data. At the finest spatial scale we relied on Landsat (30 m) to map changes in land use and land cover. We also achieved a common understanding that greening and browning trends have a complex linkage with changes in key ecosystem services. We supplemented our work with insights from local communities drawn from participatory processes and focus group discussions.

We specifically sought answers to the following questions:

1. What are the key ecosystem services, how are they distributed and who benefits from them?
2. How is the use of ecosystem services governed and what are the consequences of this governance for different social groups and the ecosystem services themselves?
3. What changes in quantity, quality and distribution of ecosystem services have been seen in the last few decades and are expected in the medium- and long-term, and what drives these changes at the study sites?
4. What strategies and governance systems could enable the equitable and sustainable use of ecosystem services and enhance human wellbeing under climate change?

We found that global, regional and local drivers have changed vegetation in semi-arid ecosystems with implications for the spatial and temporal distribution of ecosystem services. In the next section, we detail some of these changes, and their impacts, from across our wide study area.

OBSERVED CHANGES AND DRIVERS OF CHANGE IN THE SEMI-ARID REGIONS OF EACH ASSAR COUNTRY

NAMIBIA

Changes	Drivers
Reduced access to water sources	Increasing frequency and intensity of droughts, government-regulated water restrictions
Decline in Mopane caterpillars	High temperatures, floods
Decrease in fuelwood, pasture lands and thatching	Increasing population and land clearing, drought-induced habitat degradation, unsustainable harvests, expansion of agricultural lands

BOTSWANA

Changes	Drivers
Decline in pasture land, Mopane caterpillars and fuelwood	Drought-induced habitat degradation, expansion of agricultural lands, over-harvesting linked to over-permitting
Increased human-wildlife conflict, decline in plant resources	Changes in rainfall

ETHIOPIA

Changes	Drivers
Reduced access to pasture and water, degrading pasture lands	Agro-industrialisation and land privatisation, invasive species

KENYA

Changes	Drivers
Increase in conservancies and pastures	Community income-generating schemes (e.g., tourism), wildlife protection, planned grazing management
Decline in pastures and water availability	Increase in livestock, human population, perceived climate changes

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ETHIOPIA AND KENYA

Changes	Drivers
Expected increases in crop production	Irrigation, good water governance
Changes in water availability and access	Large infrastructure, agricultural intensification, competing uses for water (agricultural/industrial, household/livestock)
Increased pressure on natural resources	Population pressures

GHANA

Changes	Drivers
Decline in availability of timber and non-timber forest products	Increasing demand (domestic and commercial use of timber as fuelwood and building materials)
Loss of Forest Reserve lands	Charcoal production
Expected changes in water availability	

WEST AFRICA

Changes	Drivers
Decline in provisioning ecosystem services	Climate variability, deforestation, increased bush-burning

INDIA

Changes	Drivers
Shifting <u>boundaries of semi-arid regions</u>	Changes in precipitation regimes combined with warming and CO ₂ fertilization effects

INDIA, BENGALURU

Changes	Drivers
Changes to grazing lands (peri-urban Bengaluru), and to <u>the lake system, with impacts on hydro-services</u> (Bengaluru)	Urbanisation and unplanned development, declines in rainfall (but low-cost interventions are leading to restoration)

INDIA, MAHARASHTRA

Changes	Drivers
<u>Reduced groundwater availability</u>	Government farm-pond scheme (maladaptation), rainfall variability
<u>Increased vulnerability to agricultural yields</u>	Increases in area under cultivation, agricultural intensification, horticulture

KEY INSIGHTS

SEMI-ARID REGIONS IN INDIA AND AFRICA ARE HOTSPOTS OF CLIMATE CHANGE

Semi-arid regions, typically located on the boundary of arid and subhumid climate zones, are considered one of the more vulnerable hotspots for global change, especially climate change. These transitional climatic regions are relatively highly populated, with livelihoods strongly dependent on climate-controlled, often degraded, natural (ecosystem) resources. We assessed spatially-averaged and spatially-explicit trends in climate over 1901-2013 in four semi-arid regions in India, East Africa, southern Africa and West Africa, and compared the rates of change with those from surrounding non-semi-arid areas.

Since 1960, all semi-arid regions have showed temperature increases ranging from 0.15°C to 0.24°C per decade, similar to global averages, with semi-arid regions in [West and southern Africa](#) warming faster than surrounding areas, and vice versa for [India](#) and [East Africa](#). There are, however, locations of much faster warming – “hotspots within hotspots” – in all semi-arid regions. Rainfall shows decreasing trends in the African semi-arid regions, similar in direction and magnitude to surrounding areas, but the trends are not spatially statistically significant. Over [India](#), semi-arid regional

rainfall exhibits an increasing trend, in contrast to drying in the surrounding areas. There is a decoupling between the ways that temperature and precipitation covary between semi-arid regions and surrounding regions in recent decades in all four regions, especially in India, East Africa and southern Africa. This suggests that the four semi-arid regions may be critical areas of change for precipitation-evaporation-temperature interactions.

PROTECTED AREAS IN INDIA RESPOND DIFFERENTLY TO GLOBAL CLIMATE DRIVERS COMPARED TO SIMILAR AREAS IN AFRICA AND INDIA

Natural and human-dominated semi-arid ecosystems show clear signals of CO₂ fertilisation effects across protected areas and their buffers in India and Africa. Although the amplitude of the annual seasonal cycle is increasing over time in all regions, there are clear differences in the response of protected areas and their agro-pastoral buffers in India and the three African regions. In India, the protected areas have a smaller amplitude of annual seasonal change compared to the buffer, which we attribute to their relatively greater moisture-storage regimes; these trends are reversed in the African semi-arid regions where protected areas and buffer zones respond similarly.



The amplitude of annual seasonal phenology is increasing over time; some of this is due to decreases in dry-season vegetation, and some to greater greening at the peak of the growing season. A comparison of protected areas with agro-pastoral buffers (20 km) around them, indicated that semi-arid protected areas in India have a relatively lower amplitude of annual seasonal change, which we attribute to the higher elevations, and the protected watersheds in which these protected areas tend to be located.

Greening and browning had very different impacts on key ecosystem services in the regions. In some cases greening was associated with increased productivity and improved ecosystem services, while in other cases it was driven by a proliferation of detrimental invasive species. These vegetation changes impact communities, households and individuals through changes in the availability of ecosystem services such as biomass, water and food, which are mediated by social differentiation and governance regimes. We found clear evidence for CO₂ fertilisation causing higher greening trends, particularly across sites in the 350-800 mm rainfall gradient, supporting the hypothesis that this effect would find its highest expression in moisture-stressed sites.

Recommendations

- Better communication of global and local drivers of ecosystem change and emerging trends amongst policy makers and communities may result in more robust adaptation practices. For example, a better understanding of the effects of CO₂ fertilisation and sequestration can help understand a few of the positive impacts that IAS have on global change.
- The connectivity in ecological and hydrological processes between protected areas and their buffer areas should be reflected in land-use policies in the buffer zones. Specifically, recharge areas for groundwater inside protected areas should be recognised for their role in sustaining agriculture outside.
- The capacity of multi-disciplinary teams of practitioners, land managers, and scientists needs to be built to: improve their understanding of the ongoing changes in socio-ecological systems, including the dominant local, regional and global drivers of ecosystem change (and their feedback mechanisms); and enhance their abilities to generate future scenarios of change.
- The overall implications of greening linked to bushy encroachment of invasive tree species should be considered when designing adaptation options under near-future and multi-decadal time-scales.

MANAGING NATURAL RESOURCES AND INVASIVE SPECIES REQUIRES APPROACHES THAT ACTIVELY ENGAGE WITH, RECOGNISE, AND RESPOND TO THE DIFFERENTIATED NEEDS OF AFFECTED COMMUNITIES, INCLUDING TRADITIONALLY-MARGINALISED STAKEHOLDERS

Including affected populations more concretely in decisions about interventions for natural-resource challenges will help to identify the main trade-offs, support more effective design and implementation of interventions, avoid unintended consequences – especially for the most vulnerable – and help to ensure that the needs of those typically excluded from decision making are heard and met.

Pasture scarcity is a major issue for pastoral and agro-pastoral populations in the semi-arid regions of Kenya, impacting on livestock and the wellbeing of populations, contributing to increased levels of population mobility, creating conditions for conflict, and leading to other negative impacts. In Ethiopia, one of the biggest problems facing the Middle Awash Valley is the spread of the invasive thorny shrub *Prosopis juliflora*, which is increasing rapidly in the region, reducing the availability of pasture, closing off access to water resources, and posing health threats to livestock and people. To date, management interventions have seldom been effective. In both countries we focused on understanding both of these problems and their potential solutions, including understanding how different ways of managing the problems are viewed by different people, and what helps or hinders different approaches.

We conducted Participatory Scenario Analysis (PSA) with three communities in each study area to explore the positive and negative trade-offs associated with different scenarios or visions for future *Prosopis* management (Ethiopia), and future resource management (Kenya), and assess the relative preferences for these. In both sites, we augmented our PSA work using key informant and semi-structured group interviews on how the respective problems were perceived, and which solutions were most preferred. We also analysed remotely-sensed data to understand the distribution (and change) of *Prosopis* in the study area.

In [Kenya](#) we found urgent and effective approaches are required to address the issue of pasture scarcity. As the [climate becomes more unpredictable](#) and interacts with other causes of vulnerability, maintaining access to adequate pasture is likely to become even more pressing. However, attempts to manage the availability of pasture fairly have only been partially effective because such initiatives have commonly suffered from design and operational issues. For example, attempts to stimulate sustainable land management have been hampered by the competing stakeholder interests and power imbalances that prioritise the interests of certain groups over others, increasing the likelihood that interventions will fail, with potentially negative consequences for populations already experiencing pasture scarcity.

In [Ethiopia](#), [attempts to control or contain *Prosopis*](#) have struggled not only because of the rapidity and tenacity of its spread but also because such initiatives have commonly suffered from design and operational issues. For example, attempts to stimulate sustainable use have been hampered by the use of inappropriate technologies that have failed to operate effectively, and economic barriers that deny widespread access to livelihood opportunities associated with the harvesting of *Prosopis* wood and seed pods. Moreover, many interventions have been designed with generally little voice given to grassroots perspectives, increasing the likelihood that interventions will fail, with potentially negative consequences for populations already experiencing the impacts of the invasive plant.

We learned that making *a priori* assumptions about how people in a particular setting are likely to perceive and prioritise a specific form of intervention is a risky endeavour. In both Kenya and Ethiopia, the divergent viewpoints exhibited between participants within the same workshops highlighted the importance of consulting in a way that is sensitive to the socially-differentiated nature of communities. Any intervention will result in winners and losers; recognising this should form an important element of design and implementation.

Recommendations

- Affected populations experience the impacts of management decisions in socially-differentiated ways and, crucially, have a plurality of views and opinions on the most appropriate responses to the issue in hand. Any intervention will result in winners and losers. Recognising the potential for unintended social consequences should form an important element of the design and implementation of any intervention, with efforts taken to minimise negative impacts on the most vulnerable groups.

- The views and perspectives of affected communities must be included within decisions on the most appropriate ways and means to manage environmental change. To achieve this, meaningful and effective consultation that carefully considers power imbalances is required to allow a plurality of opinions and voices to be heard. One way to achieve this is to consult with socially-differentiated groups of people separately.
- In the context of *Prosopis*, this widespread consultation is particularly important because the invasive plant is likely to result in ecosystem 'bads' and disservices as well as ecosystem 'goods' and services, which will be distributed unevenly across affected populations. Policy and action cannot rely on de-contextualised narratives and aggregated notions of wellbeing that pre-define and structure how institutional actors see, understand and, by implication, frame solutions.
- Any intervention will produce trade-offs. Exposing and making these trade-offs explicit, particularly those that affect marginalised populations, can aid institutional actors in identifying not only which interventions are preferred, but by whom and at what cost or benefit.
- Present available technology makes it difficult to completely remove *Prosopis* from the landscape. This may never be a viable goal. It is advisable instead to propose a mosaic of management methods suited to specific geographical settings: strategies that are likely to comprise both its use in some less productive areas, and removal from some of the most productive areas used for irrigation cropping and rangelands.

FUNCTIONING ECOSYSTEM SERVICES CAN ENHANCE CLIMATE RESILIENCE IN CITIES

Preserving functioning ecosystem services within the urban fabric is crucial for climate resilience planning. However in Bengaluru, these ecosystem services are being challenged by unplanned, haphazard urbanisation. Promoting ecosystem-service-based stormwater management practices, and exploring alternative strategies that can enable stormwater attenuation or retention are necessary.



Urbanisation, especially in developing countries, is often accompanied by degradation of the surrounding environment and overall loss of biodiversity. When urbanisation is rapid (due to increased economic activity), institutional capacities are often found lacking, and unplanned development occurs. The result is the degradation and loss of crucial ecosystem services such as water provision, disaster protection, water treatment and healthy environments. A changing climate will exacerbate and compound these urbanisation issues while the decline in ecosystem services is likely to make cities less resilient in the future.

Bengaluru is the fastest growing city in India. This growth is fueled by a sharp rise in economic activity, which inadvertently has had a major impact on ecosystems and biodiversity. While historically, the city attracted people for its pleasant climate provided by the large expanses of green cover and water bodies, the subsequent influx of growth has led to a reduction in green cover due to the disproportionate increase in impervious surfaces, along with the encroachment and degradation of water bodies. Furthermore, due to

weak governance and haphazard planning, the city has grown in an inequitable fashion where the peripheries have seen rapid urbanisation along with a high degree of fragmentation of processes and services.

Peri-urban growth in Bengaluru has had implications on the integrity of the watersheds that define the northern edge of the city. The management of water in a city, both for anthropocentric uses, and for those that cater to the health of the environment, should be critical components of planning practices. It is with this lens that we [conducted geospatial analyses](#) on a sub-watershed which is a part of the larger Yale Mallappa Shetty Kere (YMSK) watershed.

We found that changing rainfall regimes are increasing water extraction patterns. In addition, changes in land use and land cover, and reduced infiltration caused by rapid urbanisation, have led to a decline in groundwater levels. Encroachment of previously green and open spaces coincides with regions that have reported floods in the last few monsoon seasons. Land-use changes – typically in the form of an increase in impervious area, reduction in local water retention in lakes, a decrease in vegetation cover, and alteration in drainage patterns – have led to enhanced threats of flooding and water shortages in the city. Stormwater often mixed with sewage flowing through the urban landscape has also led to widespread contamination of water bodies, causing degradation of ecosystem services attached to these water bodies.

Recommendations

- Ecosystem-service-based stormwater management practices should be promoted to [better conserve stormwater as a resource](#), while in the process providing additional ecosystem service benefits including hydrological services, climate regulation, and flood mitigation.
- There is a need for [exploring alternative strategies](#) that enable stormwater attenuation or retention within urban environments. Low Impact Development (LID) is one such suggested approach. Green Infrastructure-based development (such as LID) is intended to mimic the pre-urbanisation hydrology of the location or city, thereby providing a valuable ecological service. It is possible to identify potentially viable spaces within urban catchments and to map them at a high resolution with the intention of rejuvenating hydrological flows in cities. This is technically feasible for Bengaluru, but the social implications of doing so need to be extensively studied first.

CLIMATE CHANGE, LAND USE/LAND COVER CHANGES, AND OVEREXPLOITATION OF GROUNDWATER EXACERBATE VULNERABILITIES

In Maharashtra, increased access to groundwater has caused the area of land used for agriculture and horticulture to mushroom over the past 25 years. A major part of the Sangamner transect is now classified as groundwater 'overexploited.' Global warming of 1.5°C and higher is expected to add further challenges to existing groundwater vulnerability here, and exacerbate the impacts of recurrent droughts and heat stress.

Between 1991 and 2016, the Mula-Pravara river basin, located in the semi-arid region of Maharashtra state, has seen the area of land used for agriculture and horticulture increase by about 98% and 1601%, respectively. At the same time, unculturable and culturable wasteland (UCW) declined by 34.6%, and fallow lands declined by 60.5%. These changes can be majorly attributed to increased access to groundwater, irrigation projects, and watershed development programmes.

In the Sangamner sub-region, an assessment of precipitation trends indicated a modest increase in annual average rainfall since the early 1990s. It also recorded high variability in the contribution of sparse rain and moderate rain events. Due to increased groundwater dependence in the Sangamner transect, the major part of the block is now groundwater 'overexploited'.

We found that almost 87% of the area in the study villages is classified as having 'high' to 'extreme' groundwater vulnerability. These zones have very low hydraulic yields, with low capacities for groundwater storage in the hard rock basaltic aquifers. This makes it all the more important to use the groundwater resource judiciously. Vastly different vulnerabilities and current trends of groundwater use exist in the region that can shift areas of 'low' vulnerability to 'high' and 'extreme' vulnerability in the coming years. Current practices of groundwater exploration and use (pumping excessively; storing groundwater in farm ponds; drilling new and deeper wells) can impact base water flows, and dramatically reduce water availability.

Amongst various schemes, farm ponds are being encouraged at a large scale by the government in order to drought-proof the region. In principle, farm ponds are traditional rainwater harvesting structures that are supposed to have an inlet to allow runoff to ingress in the pond, and an outlet to let out excess water. Their purpose is to help farmers adapt to the vagaries of the monsoon by harvesting rainwater. But these farm ponds have changed from their intended design and are now widely used as storage tanks to hold groundwater, which is extracted indiscriminately from the multi-layered aquifer system.

We found that the benefit-cost ratios were higher in the case of smaller farm ponds as compared to large farm ponds. When considering externalities of pumping out groundwater and storing it in surface water structures (e.g., value of evaporation losses, and opportunity costs of land lost to farm pond structure) as costs, then the Net Present Values (NPV) decreased for all sizes of farm ponds. Only the smaller farm ponds were found to be viable with a positive NPV and benefit-cost ratio.

Global warming of 1.5°C and higher is expected to result in local temperatures in much of India rising more than the global average. This will likely usher in further climate challenges that exacerbate current community vulnerabilities to land use/land cover change, and groundwater overexploitation.

Recommendations

- It is essential for India's current national and state action plans on climate change and adaptation to consider the local implications of global warming of 1.5°C and 2°C in India and make informed policy decisions around these.
- Overdependence on groundwater could have serious implications for regional agricultural sustainability. State government needs to prioritise groundwater management by formulating strategies to operationalise the recently-enacted Maharashtra Groundwater (Development and Management) Act, 2009 to regulate groundwater. This is a first step towards addressing groundwater governance issues, and will require tackling the conflicting development programmes and subsidies that sometimes inadvertently lead to groundwater overexploitation.
- In zones identified as being 'highly' or 'extremely' vulnerable to groundwater scarcity, the use of inefficient and unsustainable irrigation practices, like flood irrigation, should be reduced. Farming of water-intensive crops, such as sugarcane and sweet lime, should be avoided.

- A better, more fine-scale/local level understanding of underground common-pool, multi-layered aquifers, and groundwater flow patterns, can guide the regulation of borehole drilling, determine the best placement of water-saving measures, and assist communities with their water-management efforts in lieu of changing rainfall regimes.
- Farm ponds converted to groundwater storage structures should be closely managed to minimise and prevent misuse. For this to happen, the gram panchayat (village governing body) needs to proactively engage in monitoring and regulating the extraction of groundwater for storage in farm ponds, as well as farm pond size.
- It is important to generate knowledge and evidence about groundwater status at the local level, create awareness among different stakeholders (farmers, concerned government authorities, researchers), and create a platform for dialogue for local solutions at the community level. Such a platform could help to bridge knowledge gaps pertaining to hydrogeological information at the community level, and contribute to making more robust groundwater management plans at the village and aquifer levels.



EFFECTIVE ADAPTATION TO, AND MANAGEMENT OF, INVASIVE ALIEN SPECIES REQUIRES BOTH TOP-DOWN AND LOCAL PARTICIPATORY APPROACHES

In the Moyar Bhavani, Invasive Alien Species (IAS) are negatively impacting native biodiversity and ecosystem services. The ability of local forest-dependent communities to develop management practices and adaptation strategies to the emerging novel ecosystems is constrained by lack of land tenure due to the delayed implementation of the Forest Rights Act (2006) in Tamil Nadu, and confounded by the protected area status of a large part of the landscape. Meanwhile, the capacity of the Forest Department, NGOs and local communities in understanding the temporal and spatial dynamics, and magnitude of the problem, is constrained. Potential short- and long-term management strategies remain reactive, and are uninformed by scientific studies.

Forests in the semi-arid tropics play a key role through provisioning services to tribal communities, which are strategically used to buffer risks. *Prosopis* (*Prosopis juliflora*) was introduced to the landscape in the 1960s and was expected to contribute to provisioning services through fuel and animal feed, thus increasing the productivity of grasslands. The expansion of *Prosopis* is driving a significant greening of vegetation along the Moyar valley. *Prosopis* in the region is now impacting biodiversity (blackbuck in the region prefer native species, and avoid *Prosopis*-dominated landscapes) and community livelihoods (crop raiding on farm lands from herbivores is linked to increases in *Prosopis* growth). The impacts of *Prosopis* may also worsen in the near future as the consumption of pods by wild herbivores is augmenting the dispersal of this species by blackbuck and elephants.

At higher elevations, the expansion of *Lantana* (*Lantana camara*), another IAS, has impacted local livelihoods significantly. Livestock pasturing areas have reduced, and NTFP productivity in the region has been impacted by the spread of IAS. Resistance from state agencies (especially the Forest Department) to implement the Forest Rights Act, and the pertinacious focus on physical solutions for IAS spread in the region has neglected the potential of community-led solutions.

Furthermore, the spatial and temporal dimensions of the spread of IAS, and their impacts on NTFP, livestock grazing, and wild herbivores, is not adequately acknowledged and more research is needed on the factors that drive their occupancy and persistence.

Recommendations

- The Forest Department invests significant effort in control of IAS in protected areas, albeit sporadically. An ecological monitoring effort is needed to assess the effectiveness of current strategies.
- Information on IAS is patchy and restricted to protected areas, and the potential of technological advances (e.g., smartphones and tablets) to map and monitor the spread of IAS frugally and efficiently remains underused.
- The management of IAS needs to move from the rhetoric of state-funded extraction alone to community-led solutions that take into consideration the potential for livelihood generation through the removal of IAS by communities. A [novel ecosystem framework](#) is needed to assess the potential of IAS for livelihoods, biodiversity and ecosystem services.

CLIMATE CHANGE AND VARIABILITY ARE DISCORDANT WITH OBSERVED CHANGES IN LAND USE AND LAND COVER

Large parts of Tamil Nadu receive the bulk of their annual rainfall during the northeast monsoon (Oct-Dec), but our analysis reveals a shift in the monsoon, with less rain falling during the winter months. The winter rains are crucial for agriculture, and this reduction in moisture, combined with warming, is likely to pose a challenge to the resilience of these socio-ecological systems. These shifts in rainfall regimes are, however, being currently buffered by increasing dependence on groundwater, which is driving greening in cultivated areas. Farmers are reducing risks by opting for non-agrarian livelihoods, and increasing – and likely unsustainable – dependence on groundwater. Future climate is likely to reduce moisture availability and elevate temperature, but SWAT (Soil and Water Assessment Tool) hydrological models are not adequate to capture changes in evapotranspiration under different land-cover change scenarios.



We noted a significant decline in the southwest (Jun-Sep) monsoon in the semi-arid regions of north-west and central India from 1951-2007. Although these declines are not observed in Tamil Nadu, large parts of the state are witnessing declining contributions from the northeast (NE) monsoon in areas historically adapted to receiving the bulk of their annual rainfall in these (Oct-Dec) months. This shift in monsoonal regime is also accompanied by delays in the onset and amount of rainfall received through the NE monsoon, driving changes in cropping patterns. Our analysis also revealed significant increases in mean annual temperature, and summers are now reported to be hotter and starting earlier.

Despite the declines in precipitation we observed, we noted [significant greening](#) in the Moyar-Bhavani semi-arid region (from 2001-2015), with rapid change occurring from 2006-2015. In the agrarian socio-ecological systems (SES) along the Bhavani River, this reflects an increasing dependence on lift irrigation from the river, and groundwater extraction for crop irrigation. The current risk-management strategies of farmers, which include non-agrarian livelihood diversification, groundwater dependence, and shifting of cropping patterns, have adverse implications for household wellbeing and gender relations within the household, which may not be sustainable.

We also conducted an assessment of the impacts of future climate and potential land-use change on hydrology in the Moyar-Bhavani by combining statistically-downscaled climate variables with a

SWAT hydrological model. Our assessments reveal a projected decline in precipitation, and an increase in minimum temperatures by 2100 under the conservative RCP2.6 ([Representative Concentration Pathway 2.6](#)) with respect to the baseline (1970-2000). Currently, evapotranspiration is observed to be more than half of the incident precipitation, followed by soil moisture, runoff and deep recharge. This is expected to change dramatically under [future climate scenarios](#) with nearly 90% being consumed by evapotranspiration at the cost of contributions to soil moisture and runoff. Changes in landuse and landcover were explored using a scenario-based approach that incorporated (10%, 25%, and 50%) changes in the extent of forest cover, agriculture, plantations and barren land, but these results were inconclusive. Evapotranspiration under future climate is likely to be a key driver of water stress.

Recommendations

- More effort needs to be invested in studying the NE monsoon, as monsoon research tends to be focused on studying the southwest monsoon. This will help in the development of appropriate adaptation options for communities that depend on these rains.
- Shifts in monsoonal regimes need to be investigated under ongoing and future climate change as these are expected to impact regional ecology, agriculture and adaptation options.
- Further work is needed to assess the hydrological response of changing land cover (e.g., by using different hydrological models) under future climates, by choosing physical hydrologic models or combinations of models that are able to mimic the key hydrologic fluxes in a particular basin (e.g., evapotranspiration in semi-arid regions).
- Adaptive management of groundwater under a changing climate is a key ingredient of adaptation.



ECOSYSTEM SERVICES NEED TO BE MANAGED MORE SUSTAINABLY AND EQUITABLY, AND ALTERNATIVE LIVELIHOODS MAY BE NEEDED

Provisioning ecosystem services are fundamental to the livelihoods and wellbeing of communities in the Bobirwa sub-district of Botswana. The enforcement of restrictions on harvesting, monitoring of government programmes to improve agricultural productivity, and the enhancement of alternative livelihood options could all help to reduce the pressure and overreliance on vulnerable ecosystem services.

With few alternative livelihood options, communities in the Bobirwa sub-district are [heavily reliant on ecosystem services](#), whether directly or indirectly. Crop and livestock production, and the exploitation of timber and non-timber forest products are particularly important for maintaining food security and wellbeing. However, in recent years, there have been adverse changes in the quantity, quality, distribution and timing of certain ecosystem services. Contributing factors include less predictable rainfall, more pervasive droughts, an increased demand for agricultural land, and an expansion of villages. Phane caterpillars, which local people have harvested for centuries, are one important ecosystem service that has seen a [significant decline in the last decade](#). An overexploitation of woodlands has also been observed, while the clearing of shrubs for crop cultivation has resulted in trade-offs with other provisioning ecosystem services, such as communal grazing land.

Dependence on and access to ecosystem services [varies by gender](#). Women are most affected by changes in the availability of water for the household, firewood, wild vegetables and palm leaves for basket-making. On the other hand, men are disproportionately affected by changes in the availability of timber, pasture and water for livestock. Both men and women are affected by the fluctuating availability of phane caterpillars, firewood, and fertile soils for crop production. Part of the challenge around declining natural resources is that there is a mismatch between how national authorities and local communities view ecosystem services. While the latter feel that in Bobirwa these belong to them, at the national level ecosystem services are considered a common resource. Competition from people residing beyond the sub-district therefore means that local communities have little incentive to sustainably manage ecosystem services.

Recommendations

- Ecosystem services need to be sustainably managed through regulatory measures, including permitting and restricting the timing of harvesting activities, as well as the volume of resources collected. Given their dwindling numbers, it may be necessary to place a ban on the harvesting of phane caterpillars for two or three consecutive breeding seasons to allow the population to recover, and to avoid losing this important source of protein and income entirely.
- All decisions around ecosystem services should be made through inclusive and participatory processes that emphasise the integration of community knowledge and values into plans for the management and use of ecosystem services under a changing climate. This is important for ensuring buy-in among traditional leaders, local authorities, and importantly, the grassroots people dependent on ecosystem services.
- Shifts in the availability of ecosystem services in Bobirwa impact people differently. For example, women and children are particularly vulnerable to declines in the availability of phane caterpillars as they are sometimes forced to camp far away from their homesteads in unhealthy conditions in order to access this dwindling resource. Such socially-differentiated vulnerabilities should be a key focus of policy and planning around ecosystem services.
- To ensure more sustainable management of ecosystem services, possible ways of engaging communities and resource users in enforcing regulatory measures, and monitoring the state and trends in ecosystem services should be explored.

- Key to supporting the communities that depend on declining ecosystem services is to ensure that they have other ways to make a living or survive off the land. Access to alternative livelihood options is required, although enhanced diversification (especially for women) needs to be accompanied by support systems that ensure they are not overburdened. The monitoring of government programmes aimed at increasing agricultural productivity should also be improved. This is also important for reducing the increasing pressure being placed on towns and cities from the in-migration of rural youth in search of work.

STRENGTHENED MANAGEMENT OF SCARCE WATER RESOURCES IS CRITICAL FOR REDUCING CONFLICT AND ENABLING ADAPTATION

Rising temperatures, unpredictable rainfall, and increased pressures from growing populations are shaping a complex landscape around water resources, especially groundwater and water from the Black Volta River which forms the border between Ghana and Burkina Faso. Supporting greater technical capacities and more integrated management of these resources will be essential for lessening negative impacts of climate change in the future, and for reducing conflicts among users.



Droughts, floods, and increasingly variable rainfall are impacting the quantity and quality of water sources in Upper West Ghana. Nitrate levels are elevated across many water sources due to the proximity of farming activities, and microbial levels from the Black Volta exceed the guidelines for domestic use. These issues can be harmful to human health and can impact negatively on adaptive capacities. Likewise, seasonal drying of rivers and streams, and of some boreholes during more extreme conditions, is contributing to increased conflict between water users at boreholes, as well as between livestock and irrigation farmers along rivers. For example, recent decreases in the water level of the Black Volta have resulted in a struggle between dry season farmers and semi-nomadic Fulani herdsman. Factors such as age, ethnicity and gender can greatly shape how and to what degree these challenges impact different people. For example, it is women and girls who are primarily in charge of fetching water for households, while young men are often in charge of moving livestock.

Concerning governance and management, decisions are spread across different decision makers at multiple scales. For example, regulations designed at the district level are enforced by local-level Water and Sanitation Committees (WATSAN). Then, there are traditional authorities who pass and enforce bylaws. These multiple layers of governance all aim for increased protection of water in the region. However, there are disconnects between community-level capacities and district-level management goals, and between traditional and formal government strategies. Lack of sufficient funding and technical expertise to maintain water harvesting infrastructure is perceived as contributing to a greater risk of increasing conflict around water in the future.

Recommendations

- To reduce vulnerability of smallholder farmers in the Upper West region to increasing water scarcity and other interrelated challenges, policies and programmes should target smallholder farmers at the level of disaggregated social groups, instead of considering them as a homogeneous group.
- The Ministry of Food and Agriculture and other development organisations should focus on reducing vulnerability to drought and flooding through: 1) the provision of accurate and timely rainfall information, 2) strengthening of technical capacities for maintaining water infrastructure, and 3) more transparent communication and inclusion of different water user groups in the development and updating of regulations.

- Education of community members by government and non-governmental organisations on water quality issues and related health hazards should be prioritised where possible.
- Government institutions, including district assemblies and departments of agriculture, along with the Ghana Irrigation Development Authority (GIDA), should take measures to integrate traditional irrigation approaches that are socially and culturally accepted with more modern mechanised approaches, climate smart agriculture, and well-targeted financing in order to increase uptake among farmers.

ADAPTATION TO CLIMATIC STRESSORS IS IMPORTANT, BUT IT IS EQUALLY IMPORTANT NOT TO OVERLOOK NON-CLIMATIC FACTORS THAT AFFECT PEOPLE'S LIVES AND ABILITY TO ADAPT

Climatic changes are not the only stressors that factor into adaptation needs in Koutiala, Mali. Urbanisation, changing social structures, and governance of resources are also impacting the abilities of different people to adapt. Moreover, sometimes adaptation strategies can bring about unanticipated non-climatic changes that can create new challenges that people must also cope with.

In the village of Zangasso, climatic changes (e.g., declining rainfall) are negatively affecting fishing resources. However, a number of combined non-climatic changes are also having a large impact on the fishery, and the ability of people to build their livelihoods around it. Changes in who is using the fishery are complicating its management. For example, beyond the traditional ethnic groups known to be fishers by profession and through generations, fishing is now practiced by all ethnic groups in the village including Bambara and Minianka, who are traditionally known to be farmers. With this shift, the division of labour along ethnic lines is becoming blurred. At the same time, climatic changes are combining with other factors that are degrading the fishery, including the obstruction of water sources resulting from erosion and the construction of new urban infrastructure (e.g., roads and bridges). This is also contributing to traditional fishers, the Bozo and Somono, converting to farming.

The entry of new groups of fishers, who are introducing prohibited fishing tools and techniques, is contributing to overfishing. These changes are also making it challenging to enforce the traditional governance of water resources that involve the prohibition of fishing during the reproductive periods of fish. Combined, these factors are affecting the viability of fishing as an alternative income-generating activity, and form of adaptation, for local people.

In another [area of Koutiala](#), farmers have been engaging in low-land farming where small-scale irrigation can be used as a way to adapt to climatic changes impacting their farms. Along with this adaptation strategy, though, have come new and unforeseen challenges. For example, an invasive weed species has emerged in areas where new irrigation facilities are built for repetitive rice production. This has created a situation where an adaptation strategy aimed at coping with climatic changes has produced a non-climatic stressor that now also needs to be dealt with.

Additional insights on agricultural intensification and ecosystem services were gained through documenting the [contribution and importance of agro-biodiversity](#) to climate change adaptation in Koutiala. This work assessed (including through farmers' perceptions) the impact of

climate change and variability on agro-biodiversity and its services in rural Mali, and modelled the impact of harnessing agro-biodiversity on household vulnerability in its semi-arid areas. This work found that thinking of agrobiodiversity-based (or ecosystem-based) versus other adaptation practices/strategies as mutually exclusive might be misleading and not tell the full story on the ground. Agrobiodiversity-based adaptation practices always occur in combination with other practices. Further, both climatic and non-climatic risks drive adoption of agrobiodiversity-based practices.

Recommendations

- Policy makers and other decision makers need to take a systems view when thinking of adaptation, as pursuing adaptation in one area may create unforeseen challenges in another. Continuous learning and adjustment of adaptation planning is required.
- Climatic changes are combining with changing social traditions and urbanisation in unpredictable ways. This should be recognised when designing new policies or programmes aimed at natural resource governance or adaptation.



- While introducing new and more climate-resilient crop varieties is an important step toward sustained adaptation, the importance of traditional varieties for maintaining biodiversity and providing broader adaptation options should not be ignored.
- A holistic approach is crucial for taking stock of the synergies created through integrating multiple practices/strategies (agrobiodiversity/ ecosystem-based) across scales. The effectiveness of these synergies in reducing vulnerability to risks or improving adaptive capacity needs further investigation.

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Photographs in this section: Irene Kunamwene, Nitya Rao, Hillary Masundire, Ephias Mugari, Hanna Smith, Lucia Scodanibbio, Renie Thomas, Indian Institute for Human Settlements, Institute for Environment and Sanitation Studies (University of Ghana)



Design and layout:
Rothko Brand Partners
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This work was carried out under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA), with financial support from the UK Government's Department for International Development (DfID) and the International Development Research Centre (IDRC), Canada. The views expressed in this work are those of the creators and do not necessarily represent those of DfID and IDRC or its Board of Governors.

ETHIOPIA AND KENYA

Changes	Drivers
Expected increases in crop production	Irrigation, good water governance
Changes in water availability and access	Large infrastructure, agricultural intensification, competing uses for water (agricultural/industrial, household/livestock)
Increased pressure on natural resources	Population pressures

GHANA

Changes	Drivers
Decline in availability of timber and non-timber forest products	Increasing demand (domestic and commercial use of timber as fuelwood and building materials)
Loss of Forest Reserve lands	Charcoal production
Expected changes in water availability	

WEST AFRICA

Changes	Drivers
Decline in provisioning ecosystem services	Climate variability, deforestation, increased bush-burning

INDIA

Changes	Drivers
Shifting <u>boundaries of semi-arid regions</u>	Changes in precipitation regimes combined with warming and CO ₂ fertilization effects

INDIA, BENGALURU

Changes	Drivers
Changes to grazing lands (peri-urban Bengaluru), and to <u>the lake system, with impacts on hydro-services</u> (Bengaluru)	Urbanisation and unplanned development, declines in rainfall (but low-cost interventions are leading to restoration)

INDIA, MAHARASHTRA

Changes	Drivers
<u>Reduced groundwater availability</u>	Government farm-pond scheme (maladaptation), rainfall variability
<u>Increased vulnerability to agricultural yields</u>	Increases in area under cultivation, agricultural intensification, horticulture

KEY INSIGHTS

SEMI-ARID REGIONS IN INDIA AND AFRICA ARE HOTSPOTS OF CLIMATE CHANGE

Semi-arid regions, typically located on the boundary of arid and subhumid climate zones, are considered one of the more vulnerable hotspots for global change, especially climate change. These transitional climatic regions are relatively highly populated, with livelihoods strongly dependent on climate-controlled, often degraded, natural (ecosystem) resources. We assessed spatially-averaged and spatially-explicit trends in climate over 1901-2013 in four semi-arid regions in India, East Africa, southern Africa and West Africa, and compared the rates of change with those from surrounding non-semi-arid areas.

Since 1960, all semi-arid regions have showed temperature increases ranging from 0.15°C to 0.24°C per decade, similar to global averages, with semi-arid regions in [West and southern Africa](#) warming faster than surrounding areas, and vice versa for [India](#) and [East Africa](#). There are, however, locations of much faster warming – “hotspots within hotspots” – in all semi-arid regions. Rainfall shows decreasing trends in the African semi-arid regions, similar in direction and magnitude to surrounding areas, but the trends are not spatially statistically significant. Over [India](#), semi-arid regional

rainfall exhibits an increasing trend, in contrast to drying in the surrounding areas. There is a decoupling between the ways that temperature and precipitation covary between semi-arid regions and surrounding regions in recent decades in all four regions, especially in India, East Africa and southern Africa. This suggests that the four semi-arid regions may be critical areas of change for precipitation-evaporation-temperature interactions.

PROTECTED AREAS IN INDIA RESPOND DIFFERENTLY TO GLOBAL CLIMATE DRIVERS COMPARED TO SIMILAR AREAS IN AFRICA AND INDIA

Natural and human-dominated semi-arid ecosystems show clear signals of CO₂ fertilisation effects across protected areas and their buffers in India and Africa. Although the amplitude of the annual seasonal cycle is increasing over time in all regions, there are clear differences in the response of protected areas and their agro-pastoral buffers in India and the three African regions. In India, the protected areas have a smaller amplitude of annual seasonal change compared to the buffer, which we attribute to their relatively greater moisture-storage regimes; these trends are reversed in the African semi-arid regions where protected areas and buffer zones respond similarly.



The amplitude of annual seasonal phenology is increasing over time; some of this is due to decreases in dry-season vegetation, and some to greater greening at the peak of the growing season. A comparison of protected areas with agro-pastoral buffers (20 km) around them, indicated that semi-arid protected areas in India have a relatively lower amplitude of annual seasonal change, which we attribute to the higher elevations, and the protected watersheds in which these protected areas tend to be located.

Greening and browning had very different impacts on key ecosystem services in the regions. In some cases greening was associated with increased productivity and improved ecosystem services, while in other cases it was driven by a proliferation of detrimental invasive species. These vegetation changes impact communities, households and individuals through changes in the availability of ecosystem services such as biomass, water and food, which are mediated by social differentiation and governance regimes. We found clear evidence for CO₂ fertilisation causing higher greening trends, particularly across sites in the 350–800 mm rainfall gradient, supporting the hypothesis that this effect would find its highest expression in moisture-stressed sites.

Recommendations

- Better communication of global and local drivers of ecosystem change and emerging trends amongst policy makers and communities may result in more robust adaptation practices. For example, a better understanding of the effects of CO₂ fertilisation and sequestration can help understand a few of the positive impacts that IAS have on global change.
- The connectivity in ecological and hydrological processes between protected areas and their buffer areas should be reflected in land-use policies in the buffer zones. Specifically, recharge areas for groundwater inside protected areas should be recognised for their role in sustaining agriculture outside.
- The capacity of multi-disciplinary teams of practitioners, land managers, and scientists needs to be built to: improve their understanding of the ongoing changes in socio-ecological systems, including the dominant local, regional and global drivers of ecosystem change (and their feedback mechanisms); and enhance their abilities to generate future scenarios of change.
- The overall implications of greening linked to bushy encroachment of invasive tree species should be considered when designing adaptation options under near-future and multi-decadal time-scales.

MANAGING NATURAL RESOURCES AND INVASIVE SPECIES REQUIRES APPROACHES THAT ACTIVELY ENGAGE WITH, RECOGNISE, AND RESPOND TO THE DIFFERENTIATED NEEDS OF AFFECTED COMMUNITIES, INCLUDING TRADITIONALLY-MARGINALISED STAKEHOLDERS

Including affected populations more concretely in decisions about interventions for natural-resource challenges will help to identify the main trade-offs, support more effective design and implementation of interventions, avoid unintended consequences – especially for the most vulnerable – and help to ensure that the needs of those typically excluded from decision making are heard and met.

Pasture scarcity is a major issue for pastoral and agro-pastoral populations in the semi-arid regions of Kenya, impacting on livestock and the wellbeing of populations, contributing to increased levels of population mobility, creating conditions for conflict, and leading to other negative impacts. In Ethiopia, one of the biggest problems facing the Middle Awash Valley is the spread of the invasive thorny shrub *Prosopis juliflora*, which is increasing rapidly in the region, reducing the availability of pasture, closing off access to water resources, and posing health threats to livestock and people. To date, management interventions have seldom been effective. In both countries we focused on understanding both of these problems and their potential solutions, including understanding how different ways of managing the problems are viewed by different people, and what helps or hinders different approaches.

We conducted Participatory Scenario Analysis (PSA) with three communities in each study area to explore the positive and negative trade-offs associated with different scenarios or visions for future *Prosopis* management (Ethiopia), and future resource management (Kenya), and assess the relative preferences for these. In both sites, we augmented our PSA work using key informant and semi-structured group interviews on how the respective problems were perceived, and which solutions were most preferred. We also analysed remotely-sensed data to understand the distribution (and change) of *Prosopis* in the study area.

In [Kenya](#) we found urgent and effective approaches are required to address the issue of pasture scarcity. As the [climate becomes more unpredictable](#) and interacts with other causes of vulnerability, maintaining access to adequate pasture is likely to become even more pressing. However, attempts to manage the availability of pasture fairly have only been partially effective because such initiatives have commonly suffered from design and operational issues. For example, attempts to stimulate sustainable land management have been hampered by the competing stakeholder interests and power imbalances that prioritise the interests of certain groups over others, increasing the likelihood that interventions will fail, with potentially negative consequences for populations already experiencing pasture scarcity.

In [Ethiopia](#), [attempts to control or contain *Prosopis*](#) have struggled not only because of the rapidity and tenacity of its spread but also because such initiatives have commonly suffered from design and operational issues. For example, attempts to stimulate sustainable use have been hampered by the use of inappropriate technologies that have failed to operate effectively, and economic barriers that deny widespread access to livelihood opportunities associated with the harvesting of *Prosopis* wood and seed pods. Moreover, many interventions have been designed with generally little voice given to grassroots perspectives, increasing the likelihood that interventions will fail, with potentially negative consequences for populations already experiencing the impacts of the invasive plant.

We learned that making *a priori* assumptions about how people in a particular setting are likely to perceive and prioritise a specific form of intervention is a risky endeavour. In both Kenya and Ethiopia, the divergent viewpoints exhibited between participants within the same workshops highlighted the importance of consulting in a way that is sensitive to the socially-differentiated nature of communities. Any intervention will result in winners and losers; recognising this should form an important element of design and implementation.

Recommendations

- Affected populations experience the impacts of management decisions in socially-differentiated ways and, crucially, have a plurality of views and opinions on the most appropriate responses to the issue in hand. Any intervention will result in winners and losers. Recognising the potential for unintended social consequences should form an important element of the design and implementation of any intervention, with efforts taken to minimise negative impacts on the most vulnerable groups.

- The views and perspectives of affected communities must be included within decisions on the most appropriate ways and means to manage environmental change. To achieve this, meaningful and effective consultation that carefully considers power imbalances is required to allow a plurality of opinions and voices to be heard. One way to achieve this is to consult with socially-differentiated groups of people separately.
- In the context of *Prosopis*, this widespread consultation is particularly important because the invasive plant is likely to result in ecosystem 'bads' and disservices as well as ecosystem 'goods' and services, which will be distributed unevenly across affected populations. Policy and action cannot rely on de-contextualised narratives and aggregated notions of wellbeing that pre-define and structure how institutional actors see, understand and, by implication, frame solutions.
- Any intervention will produce trade-offs. Exposing and making these trade-offs explicit, particularly those that affect marginalised populations, can aid institutional actors in identifying not only which interventions are preferred, but by whom and at what cost or benefit.
- Present available technology makes it difficult to completely remove *Prosopis* from the landscape. This may never be a viable goal. It is advisable instead to propose a mosaic of management methods suited to specific geographical settings: strategies that are likely to comprise both its use in some less productive areas, and removal from some of the most productive areas used for irrigation cropping and rangelands.

FUNCTIONING ECOSYSTEM SERVICES CAN ENHANCE CLIMATE RESILIENCE IN CITIES

Preserving functioning ecosystem services within the urban fabric is crucial for climate resilience planning. However in Bengaluru, these ecosystem services are being challenged by unplanned, haphazard urbanisation. Promoting ecosystem-service-based stormwater management practices, and exploring alternative strategies that can enable stormwater attenuation or retention are necessary.



Urbanisation, especially in developing countries, is often accompanied by degradation of the surrounding environment and overall loss of biodiversity. When urbanisation is rapid (due to increased economic activity), institutional capacities are often found lacking, and unplanned development occurs. The result is the degradation and loss of crucial ecosystem services such as water provision, disaster protection, water treatment and healthy environments. A changing climate will exacerbate and compound these urbanisation issues while the decline in ecosystem services is likely to make cities less resilient in the future.

Bengaluru is the fastest growing city in India. This growth is fueled by a sharp rise in economic activity, which inadvertently has had a major impact on ecosystems and biodiversity. While historically, the city attracted people for its pleasant climate provided by the large expanses of green cover and water bodies, the subsequent influx of growth has led to a reduction in green cover due to the disproportionate increase in impervious surfaces, along with the encroachment and degradation of water bodies. Furthermore, due to

weak governance and haphazard planning, the city has grown in an inequitable fashion where the peripheries have seen rapid urbanisation along with a high degree of fragmentation of processes and services.

Peri-urban growth in Bengaluru has had implications on the integrity of the watersheds that define the northern edge of the city. The management of water in a city, both for anthropocentric uses, and for those that cater to the health of the environment, should be critical components of planning practices. It is with this lens that we [conducted geospatial analyses](#) on a sub-watershed which is a part of the larger Yale Mallappa Shetty Kere (YMSK) watershed.

We found that changing rainfall regimes are increasing water extraction patterns. In addition, changes in land use and land cover, and reduced infiltration caused by rapid urbanisation, have led to a decline in groundwater levels. Encroachment of previously green and open spaces coincides with regions that have reported floods in the last few monsoon seasons. Land-use changes – typically in the form of an increase in impervious area, reduction in local water retention in lakes, a decrease in vegetation cover, and alteration in drainage patterns – have led to enhanced threats of flooding and water shortages in the city. Stormwater often mixed with sewage flowing through the urban landscape has also led to widespread contamination of water bodies, causing degradation of ecosystem services attached to these water bodies.

Recommendations

- Ecosystem-service-based stormwater management practices should be promoted to [better conserve stormwater as a resource](#), while in the process providing additional ecosystem service benefits including hydrological services, climate regulation, and flood mitigation.
- There is a need for [exploring alternative strategies](#) that enable stormwater attenuation or retention within urban environments. Low Impact Development (LID) is one such suggested approach. Green Infrastructure-based development (such as LID) is intended to mimic the pre-urbanisation hydrology of the location or city, thereby providing a valuable ecological service. It is possible to identify potentially viable spaces within urban catchments and to map them at a high resolution with the intention of rejuvenating hydrological flows in cities. This is technically feasible for Bengaluru, but the social implications of doing so need to be extensively studied first.

CLIMATE CHANGE, LAND USE/LAND COVER CHANGES, AND OVEREXPLOITATION OF GROUNDWATER EXACERBATE VULNERABILITIES

In Maharashtra, increased access to groundwater has caused the area of land used for agriculture and horticulture to mushroom over the past 25 years. A major part of the Sangamner transect is now classified as groundwater 'overexploited.' Global warming of 1.5°C and higher is expected to add further challenges to existing groundwater vulnerability here, and exacerbate the impacts of recurrent droughts and heat stress.

Between 1991 and 2016, the Mula-Pravara river basin, located in the semi-arid region of Maharashtra state, has seen the area of land used for agriculture and horticulture increase by about 98% and 1601%, respectively. At the same time, unculturable and culturable wasteland (UCW) declined by 34.6%, and fallow lands declined by 60.5%. These changes can be majorly attributed to increased access to groundwater, irrigation projects, and watershed development programmes.

In the Sangamner sub-region, an assessment of precipitation trends indicated a modest increase in annual average rainfall since the early 1990s. It also recorded high variability in the contribution of sparse rain and moderate rain events. Due to increased groundwater dependence in the Sangamner transect, the major part of the block is now groundwater 'overexploited'.

We found that almost 87% of the area in the study villages is classified as having 'high' to 'extreme' groundwater vulnerability. These zones have very low hydraulic yields, with low capacities for groundwater storage in the hard rock basaltic aquifers. This makes it all the more important to use the groundwater resource judiciously. Vastly different vulnerabilities and current trends of groundwater use exist in the region that can shift areas of 'low' vulnerability to 'high' and 'extreme' vulnerability in the coming years. Current practices of groundwater exploration and use (pumping excessively; storing groundwater in farm ponds; drilling new and deeper wells) can impact base water flows, and dramatically reduce water availability.

Amongst various schemes, farm ponds are being encouraged at a large scale by the government in order to drought-proof the region. In principle, farm ponds are traditional rainwater harvesting structures that are supposed to have an inlet to allow runoff to ingress in the pond, and an outlet to let out excess water. Their purpose is to help farmers adapt to the vagaries of the monsoon by harvesting rainwater. But these farm ponds have changed from their intended design and are now widely used as storage tanks to hold groundwater, which is extracted indiscriminately from the multi-layered aquifer system.

We found that the benefit-cost ratios were higher in the case of smaller farm ponds as compared to large farm ponds. When considering externalities of pumping out groundwater and storing it in surface water structures (e.g., value of evaporation losses, and opportunity costs of land lost to farm pond structure) as costs, then the Net Present Values (NPV) decreased for all sizes of farm ponds. Only the smaller farm ponds were found to be viable with a positive NPV and benefit-cost ratio.

Global warming of 1.5°C and higher is expected to result in local temperatures in much of India rising more than the global average. This will likely usher in further climate challenges that exacerbate current community vulnerabilities to land use/land cover change, and groundwater overexploitation.

Recommendations

- It is essential for India's current national and state action plans on climate change and adaptation to consider the local implications of global warming of 1.5°C and 2°C in India and make informed policy decisions around these.
- Overdependence on groundwater could have serious implications for regional agricultural sustainability. State government needs to prioritise groundwater management by formulating strategies to operationalise the recently-enacted Maharashtra Groundwater (Development and Management) Act, 2009 to regulate groundwater. This is a first step towards addressing groundwater governance issues, and will require tackling the conflicting development programmes and subsidies that sometimes inadvertently lead to groundwater overexploitation.
- In zones identified as being 'highly' or 'extremely' vulnerable to groundwater scarcity, the use of inefficient and unsustainable irrigation practices, like flood irrigation, should be reduced. Farming of water-intensive crops, such as sugarcane and sweet lime, should be avoided.

- A better, more fine-scale/local level understanding of underground common-pool, multi-layered aquifers, and groundwater flow patterns, can guide the regulation of borehole drilling, determine the best placement of water-saving measures, and assist communities with their water-management efforts in lieu of changing rainfall regimes.
- Farm ponds converted to groundwater storage structures should be closely managed to minimise and prevent misuse. For this to happen, the gram panchayat (village governing body) needs to proactively engage in monitoring and regulating the extraction of groundwater for storage in farm ponds, as well as farm pond size.
- It is important to generate knowledge and evidence about groundwater status at the local level, create awareness among different stakeholders (farmers, concerned government authorities, researchers), and create a platform for dialogue for local solutions at the community level. Such a platform could help to bridge knowledge gaps pertaining to hydrogeological information at the community level, and contribute to making more robust groundwater management plans at the village and aquifer levels.



EFFECTIVE ADAPTATION TO, AND MANAGEMENT OF, INVASIVE ALIEN SPECIES REQUIRES BOTH TOP-DOWN AND LOCAL PARTICIPATORY APPROACHES

In the Moyar Bhavani, Invasive Alien Species (IAS) are negatively impacting native biodiversity and ecosystem services. The ability of local forest-dependent communities to develop management practices and adaptation strategies to the emerging novel ecosystems is constrained by lack of land tenure due to the delayed implementation of the Forest Rights Act (2006) in Tamil Nadu, and confounded by the protected area status of a large part of the landscape. Meanwhile, the capacity of the Forest Department, NGOs and local communities in understanding the temporal and spatial dynamics, and magnitude of the problem, is constrained. Potential short- and long-term management strategies remain reactive, and are uninformed by scientific studies.

Forests in the semi-arid tropics play a key role through provisioning services to tribal communities, which are strategically used to buffer risks. *Prosopis* (*Prosopis juliflora*) was introduced to the landscape in the 1960s and was expected to contribute to provisioning services through fuel and animal feed, thus increasing the productivity of grasslands. The expansion of *Prosopis* is driving a significant greening of vegetation along the Moyar valley. *Prosopis* in the region is now impacting biodiversity (blackbuck in the region prefer native species, and avoid *Prosopis*-dominated landscapes) and community livelihoods (crop raiding on farm lands from herbivores is linked to increases in *Prosopis* growth). The impacts of *Prosopis* may also worsen in the near future as the consumption of pods by wild herbivores is augmenting the dispersal of this species by blackbuck and elephants.

At higher elevations, the expansion of *Lantana* (*Lantana camara*), another IAS, has impacted local livelihoods significantly. Livestock pasturing areas have reduced, and NTFP productivity in the region has been impacted by the spread of IAS. Resistance from state agencies (especially the Forest Department) to implement the Forest Rights Act, and the pertinacious focus on physical solutions for IAS spread in the region has neglected the potential of community-led solutions.

Furthermore, the spatial and temporal dimensions of the spread of IAS, and their impacts on NTFP, livestock grazing, and wild herbivores, is not adequately acknowledged and more research is needed on the factors that drive their occupancy and persistence.

Recommendations

- The Forest Department invests significant effort in control of IAS in protected areas, albeit sporadically. An ecological monitoring effort is needed to assess the effectiveness of current strategies.
- Information on IAS is patchy and restricted to protected areas, and the potential of technological advances (e.g., smartphones and tablets) to map and monitor the spread of IAS frugally and efficiently remains underused.
- The management of IAS needs to move from the rhetoric of state-funded extraction alone to community-led solutions that take into consideration the potential for livelihood generation through the removal of IAS by communities. A [novel ecosystem framework](#) is needed to assess the potential of IAS for livelihoods, biodiversity and ecosystem services.

CLIMATE CHANGE AND VARIABILITY ARE DISCORDANT WITH OBSERVED CHANGES IN LAND USE AND LAND COVER

Large parts of Tamil Nadu receive the bulk of their annual rainfall during the northeast monsoon (Oct-Dec), but our analysis reveals a shift in the monsoon, with less rain falling during the winter months. The winter rains are crucial for agriculture, and this reduction in moisture, combined with warming, is likely to pose a challenge to the resilience of these socio-ecological systems. These shifts in rainfall regimes are, however, being currently buffered by increasing dependence on groundwater, which is driving greening in cultivated areas. Farmers are reducing risks by opting for non-agrarian livelihoods, and increasing – and likely unsustainable – dependence on groundwater. Future climate is likely to reduce moisture availability and elevate temperature, but SWAT (Soil and Water Assessment Tool) hydrological models are not adequate to capture changes in evapotranspiration under different land-cover change scenarios.



We noted a significant decline in the southwest (Jun-Sep) monsoon in the semi-arid regions of north-west and central India from 1951-2007. Although these declines are not observed in Tamil Nadu, large parts of the state are witnessing declining contributions from the northeast (NE) monsoon in areas historically adapted to receiving the bulk of their annual rainfall in these (Oct-Dec) months. This shift in monsoonal regime is also accompanied by delays in the onset and amount of rainfall received through the NE monsoon, driving changes in cropping patterns. Our analysis also revealed significant increases in mean annual temperature, and summers are now reported to be hotter and starting earlier.

Despite the declines in precipitation we observed, we noted [significant greening](#) in the Moyar-Bhavani semi-arid region (from 2001-2015), with rapid change occurring from 2006-2015. In the agrarian socio-ecological systems (SES) along the Bhavani River, this reflects an increasing dependence on lift irrigation from the river, and groundwater extraction for crop irrigation. The current risk-management strategies of farmers, which include non-agrarian livelihood diversification, groundwater dependence, and shifting of cropping patterns, have adverse implications for household wellbeing and gender relations within the household, which may not be sustainable.

We also conducted an assessment of the impacts of future climate and potential land-use change on hydrology in the Moyar-Bhavani by combining statistically-downscaled climate variables with a

SWAT hydrological model. Our assessments reveal a projected decline in precipitation, and an increase in minimum temperatures by 2100 under the conservative RCP2.6 ([Representative Concentration Pathway 2.6](#)) with respect to the baseline (1970-2000). Currently, evapotranspiration is observed to be more than half of the incident precipitation, followed by soil moisture, runoff and deep recharge. This is expected to change dramatically under [future climate scenarios](#) with nearly 90% being consumed by evapotranspiration at the cost of contributions to soil moisture and runoff. Changes in landuse and landcover were explored using a scenario-based approach that incorporated (10%, 25%, and 50%) changes in the extent of forest cover, agriculture, plantations and barren land, but these results were inconclusive. Evapotranspiration under future climate is likely to be a key driver of water stress.

Recommendations

- More effort needs to be invested in studying the NE monsoon, as monsoon research tends to be focused on studying the southwest monsoon. This will help in the development of appropriate adaptation options for communities that depend on these rains.
- Shifts in monsoonal regimes need to be investigated under ongoing and future climate change as these are expected to impact regional ecology, agriculture and adaptation options.
- Further work is needed to assess the hydrological response of changing land cover (e.g., by using different hydrological models) under future climates, by choosing physical hydrologic models or combinations of models that are able to mimic the key hydrologic fluxes in a particular basin (e.g., evapotranspiration in semi-arid regions).
- Adaptive management of groundwater under a changing climate is a key ingredient of adaptation.



ECOSYSTEM SERVICES NEED TO BE MANAGED MORE SUSTAINABLY AND EQUITABLY, AND ALTERNATIVE LIVELIHOODS MAY BE NEEDED

Provisioning ecosystem services are fundamental to the livelihoods and wellbeing of communities in the Bobirwa sub-district of Botswana. The enforcement of restrictions on harvesting, monitoring of government programmes to improve agricultural productivity, and the enhancement of alternative livelihood options could all help to reduce the pressure and overreliance on vulnerable ecosystem services.

With few alternative livelihood options, communities in the Bobirwa sub-district are [heavily reliant on ecosystem services](#), whether directly or indirectly. Crop and livestock production, and the exploitation of timber and non-timber forest products are particularly important for maintaining food security and wellbeing. However, in recent years, there have been adverse changes in the quantity, quality, distribution and timing of certain ecosystem services. Contributing factors include less predictable rainfall, more pervasive droughts, an increased demand for agricultural land, and an expansion of villages. Phane caterpillars, which local people have harvested for centuries, are one important ecosystem service that has seen a [significant decline in the last decade](#). An overexploitation of woodlands has also been observed, while the clearing of shrubs for crop cultivation has resulted in trade-offs with other provisioning ecosystem services, such as communal grazing land.

Dependence on and access to ecosystem services [varies by gender](#). Women are most affected by changes in the availability of water for the household, firewood, wild vegetables and palm leaves for basket-making. On the other hand, men are disproportionately affected by changes in the availability of timber, pasture and water for livestock. Both men and women are affected by the fluctuating availability of phane caterpillars, firewood, and fertile soils for crop production. Part of the challenge around declining natural resources is that there is a mismatch between how national authorities and local communities view ecosystem services. While the latter feel that in Bobirwa these belong to them, at the national level ecosystem services are considered a common resource. Competition from people residing beyond the sub-district therefore means that local communities have little incentive to sustainably manage ecosystem services.

Recommendations

- Ecosystem services need to be sustainably managed through regulatory measures, including permitting and restricting the timing of harvesting activities, as well as the volume of resources collected. Given their dwindling numbers, it may be necessary to place a ban on the harvesting of phane caterpillars for two or three consecutive breeding seasons to allow the population to recover, and to avoid losing this important source of protein and income entirely.
- All decisions around ecosystem services should be made through inclusive and participatory processes that emphasise the integration of community knowledge and values into plans for the management and use of ecosystem services under a changing climate. This is important for ensuring buy-in among traditional leaders, local authorities, and importantly, the grassroots people dependent on ecosystem services.
- Shifts in the availability of ecosystem services in Bobirwa impact people differently. For example, women and children are particularly vulnerable to declines in the availability of phane caterpillars as they are sometimes forced to camp far away from their homesteads in unhealthy conditions in order to access this dwindling resource. Such socially-differentiated vulnerabilities should be a key focus of policy and planning around ecosystem services.
- To ensure more sustainable management of ecosystem services, possible ways of engaging communities and resource users in enforcing regulatory measures, and monitoring the state and trends in ecosystem services should be explored.

- Key to supporting the communities that depend on declining ecosystem services is to ensure that they have other ways to make a living or survive off the land. Access to alternative livelihood options is required, although enhanced diversification (especially for women) needs to be accompanied by support systems that ensure they are not overburdened. The monitoring of government programmes aimed at increasing agricultural productivity should also be improved. This is also important for reducing the increasing pressure being placed on towns and cities from the in-migration of rural youth in search of work.

STRENGTHENED MANAGEMENT OF SCARCE WATER RESOURCES IS CRITICAL FOR REDUCING CONFLICT AND ENABLING ADAPTATION

Rising temperatures, unpredictable rainfall, and increased pressures from growing populations are shaping a complex landscape around water resources, especially groundwater and water from the Black Volta River which forms the border between Ghana and Burkina Faso. Supporting greater technical capacities and more integrated management of these resources will be essential for lessening negative impacts of climate change in the future, and for reducing conflicts among users.



Droughts, floods, and increasingly variable rainfall are impacting the [quantity and quality of water sources](#) in Upper West Ghana. [Nitrate levels](#) are elevated across many water sources due to the proximity of farming activities, and microbial levels from the Black Volta exceed the guidelines for domestic use. These issues can be harmful to human health and can impact negatively on adaptive capacities. Likewise, seasonal drying of rivers and streams, and of some boreholes during more extreme conditions, is contributing to increased conflict between water users at boreholes, as well as between livestock and irrigation farmers along rivers. For example, recent decreases in the water level of the Black Volta have resulted in a struggle between dry season farmers and semi-nomadic Fulani herdsman. Factors such as age, ethnicity and gender can greatly shape how and to what degree these challenges impact different people. For example, it is women and girls who are primarily in charge of fetching water for households, while young men are often in charge of moving livestock.

Concerning [governance and management](#), decisions are spread across different decision makers at multiple scales. For example, regulations designed at the district level are enforced by local-level Water and Sanitation Committees (WATSAN). Then, there are traditional authorities who pass and enforce bylaws. These multiple layers of governance all aim for increased protection of water in the region. However, there are disconnects between community-level capacities and district-level management goals, and between traditional and formal government strategies. Lack of sufficient funding and technical expertise to maintain water harvesting infrastructure is perceived as contributing to a greater risk of increasing conflict around water in the future.

Recommendations

- To reduce vulnerability of smallholder farmers in the Upper West region to increasing water scarcity and other interrelated challenges, policies and programmes should target smallholder farmers at the level of disaggregated social groups, instead of considering them as a homogeneous group.
- The Ministry of Food and Agriculture and other development organisations should focus on reducing vulnerability to drought and flooding through: 1) the provision of accurate and timely rainfall information, 2) strengthening of technical capacities for maintaining water infrastructure, and 3) more transparent communication and inclusion of different water user groups in the development and updating of regulations.

- Education of community members by government and non-governmental organisations on [water quality issues](#) and related health hazards should be prioritised where possible.
- Government institutions, including district assemblies and departments of agriculture, along with the Ghana Irrigation Development Authority (GIDA), [should take measures](#) to integrate traditional irrigation approaches that are socially and culturally accepted with more modern mechanised approaches, climate smart agriculture, and well-targeted financing in order to increase uptake among farmers.

ADAPTATION TO CLIMATIC STRESSORS IS IMPORTANT, BUT IT IS EQUALLY IMPORTANT NOT TO OVERLOOK NON-CLIMATIC FACTORS THAT AFFECT PEOPLE'S LIVES AND ABILITY TO ADAPT

Climatic changes are not the only stressors that factor into adaptation needs in Koutiala, Mali. Urbanisation, changing social structures, and governance of resources are also impacting the abilities of different people to adapt. Moreover, sometimes adaptation strategies can bring about unanticipated non-climatic changes that can create new challenges that people must also cope with.

In the [village of Zangasso](#), climatic changes (e.g., declining rainfall) are negatively affecting fishing resources. However, a number of combined non-climatic changes are also having a large impact on the fishery, and the ability of people to build their livelihoods around it. Changes in who is using the fishery are complicating its management. For example, beyond the traditional ethnic groups known to be fishers by profession and through generations, fishing is now practiced by all ethnic groups in the village including Bambara and Minianka, who are traditionally known to be farmers. With this shift, the division of labour along ethnic lines is becoming blurred. At the same time, climatic changes are combining with other factors that are degrading the fishery, including the obstruction of water sources resulting from erosion and the construction of new urban infrastructure (e.g., roads and bridges). This is also contributing to traditional fishers, the Bozo and Somono, converting to farming.

The entry of new groups of fishers, who are introducing prohibited fishing tools and techniques, is contributing to overfishing. These changes are also making it challenging to enforce the traditional governance of water resources that involve the prohibition of fishing during the reproductive periods of fish. Combined, these factors are affecting the viability of fishing as an alternative income-generating activity, and form of adaptation, for local people.

In another [area of Koutiala](#), farmers have been engaging in low-land farming where small-scale irrigation can be used as a way to adapt to climatic changes impacting their farms. Along with this adaptation strategy, though, have come new and unforeseen challenges. For example, an invasive weed species has emerged in areas where new irrigation facilities are built for repetitive rice production. This has created a situation where an adaptation strategy aimed at coping with climatic changes has produced a non-climatic stressor that now also needs to be dealt with.

Additional insights on agricultural intensification and ecosystem services were gained through documenting the [contribution and importance of agro-biodiversity](#) to climate change adaptation in Koutiala. This work assessed (including through farmers' perceptions) the impact of

climate change and variability on agro-biodiversity and its services in rural Mali, and modelled the impact of harnessing agro-biodiversity on household vulnerability in its semi-arid areas. This work found that thinking of agrobiodiversity-based (or ecosystem-based) versus other adaptation practices/strategies as mutually exclusive might be misleading and not tell the full story on the ground. Agrobiodiversity-based adaptation practices always occur in combination with other practices. Further, both climatic and non-climatic risks drive adoption of agrobiodiversity-based practices.

Recommendations

- Policy makers and other decision makers need to take a systems view when thinking of adaptation, as pursuing adaptation in one area may create unforeseen challenges in another. Continuous learning and adjustment of adaptation planning is required.
- Climatic changes are combining with changing social traditions and urbanisation in unpredictable ways. This should be recognised when designing new policies or programmes aimed at natural resource governance or adaptation.



- While introducing new and more climate-resilient crop varieties is an important step toward sustained adaptation, the importance of traditional varieties for maintaining biodiversity and providing broader adaptation options should not be ignored.
- A holistic approach is crucial for taking stock of the synergies created through integrating multiple practices/strategies (agrobiodiversity/ ecosystem-based) across scales. The effectiveness of these synergies in reducing vulnerability to risks or improving adaptive capacity needs further investigation.

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Photographs in this section: Irene Kunamwene, Nitya Rao, Hillary Masundire, Ephias Mugari, Hanna Smith, Lucia Scodanibbio, Renie Thomas, Indian Institute for Human Settlements, Institute for Environment and Sanitation Studies (University of Ghana)



Design and layout:
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This work was carried out under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA), with financial support from the UK Government's Department for International Development (DfID) and the International Development Research Centre (IDRC), Canada. The views expressed in this work are those of the creators and do not necessarily represent those of DfID and IDRC or its Board of Governors.